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Blood lactate vs. exhaustive exercise to evaluate aerobic fitness

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Summary. This study compared the predictive power of a lactate-related index determined during submaximal cycle exercise to that of an exhaustive cycle ergometer test for evaluating the endurance exercise capacity of soldiers. The subjects ($n = 48$ males) performed a continuous exercise test to voluntary exhaustion on the cycle ergometer. Power output (PO) increased by 50 W steps each fourth min, with determinations of heart rate (HR), RPE and blood lactate concentrations (HLa) just prior to each PO increase. The PO at a 4 mmol L^{-1} HLa concentration (W_{OBLA}) was interpolated; based on the time to exhaustion the maximal PO that could be maintained for 6 min (W_{max_6}) was calculated from previously documented formulae. Subjects were timed during a 3000 m cross-country run. Both the cycle test and the run were performed again 3 months later, as was an additional 3000 m run with full military equipment weighing about 21 kg. All 3000 m times were significantly correlated ($p < 0.05$) with both W_{max_6} and W_{OBLA}; similar predictive power was demonstrated for both W_{max_6} and W_{OBLA}, suggesting that accuracy in evaluation would not be sacrificed by substituting the submaximal for the exhaustive exercise test. HR and RPE-related indices showed markedly lower predictive power. The results extend the previously documented relationship between HLa during treadmill ergometry and running performance to include the use of cycle ergometry for the evaluation of running performance. The results also proved applicable to running performance while load carrying.

Key words: Endurance exercise — Ergometry — Lactate — Fitness

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Introduction

Several studies have demonstrated that the blood lactate response to submaximal treadmill exercise is strongly correlated with endurance running performance of distances ranging from 300 m to ultra-marathon distances (Farrell et al. 1979; Föhrenbach et al. 1981; Jooste et al. 1981; Kumagai et al. 1982; Sjödin and Jacobs 1981). An earlier study showed that endurance time during a continuous, progressive cycle ergometer test was also directly related to the lactate response to submaximal cycle exercise (Jacobs et al. 1983). Since such lactate-related indices are reproducible (Sjödin et al. 1982) and more strongly correlated with endurance performance than is maximal aerobic power (Farrell et al. 1979; Jooste et al. 1981; Kumagai et al. 1982) we wished to examine their use as an alternative to the exhaustive cycle test presently used in evaluating the endurance performance of military recruits in this country (Nordesjö and Schéle 1974).

The cycle offers a simpler and less expensive alternative to the treadmill for mass ergometric testing. However, our specific interest is in being able to classify recruits in terms of their running and/or walking endurance in the field. The question is thus posed whether a lactate-related index determined during cycle exercise is indicative of running performance in the field. Specifically, the present study compared the predictive power of a submaximal exercise test to that of the exhaustive cycle ergometer test presently used in evaluating the endurance exercise capacity of military conscripts.

Methods

Subjects. The subjects were 48 male volunteers from a group of soldiers selected for military police training. The subjects

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were fully informed of the details, risks and discomforts associated with the experimental protocol which was approved by the hospital's ethics committee. Mean values (±SD) for age, height, and weight were 19.9±0.6 years, 185±5 cm, and 77.1±8.2 kg, respectively. All 48 subjects participated in the initial laboratory tests but due to illness, intervening service duties, and leaves of absence, the number was reduced for the field tests and the retesting phases.

Laboratory test. Each subject performed an exercise test to exhaustion at 60 rev min^{-1} on a electrically braked cycle ergometer (Siemens Elema). The test was continuous with power output increases of 50 W each fourth min in a stepwise fashion. Exhaustion was defined as the inability to maintain 60 rev min^{-1}. During the final 30 s at each power level heart rate (HR) was measured with a cardiometer (Cardionics AB); a rating of perceived exertion (RPE) was chosen by the subject from a 10-point scale (Borg 1982) describing the relative perception of leg fatigue; finger-tip blood (25 µl) was sampled for lactate determination (Karlsson et al. 1983). Lactate concentration was plotted against cycle power output and the power output eliciting 4 mmol L^{-1} lactate (W_{OBLA}) was interpolated as described previously (Jacobs et al. 1983; Sjödin and Jacobs 1981) (OBLA = onset of blood lactate accumulation). Additional variables of particular interest were the lactate concentration at 200 W (HLa200), HR at 200 W (HR200), and RPE at 200 W (RPE200). The maximal power output that could be maintained for 6 min during an acute exercise bout (W_{max_6}) was estimated according to formulae developed by Tornvall (1963) and modified by Nordesjö (1974). Each subject's initial W_{max_6} value, from the time of enlistment at the recruitment centre, was also made available by the Draft Board authorities.

Field test. Subjects ($n=34$) were timed during a 3000 m cross-country run within two weeks of the cycle test. The run was performed en masse and all subjects ran while wearing running shoes and sweat suits.

Retesting. The laboratory and field tests were repeated five months later ($n=33$). In addition to the normal 3000 m run, they ran the same route wearing a standard uniform, military boots and while carrying a backpack and automatic rifle ($n=37$). The weight of the uniform, boots, backpack and rifle was standardized as much as the variation in boots and uniform size would permit; it averaged 20.89±1.56 kg. This run is referred to as the "loaded run".

Statistics. The BMDP statistical software package (Dixon and Brown 1979) was used for the calculation of descriptive statistics, Pearson correlation coefficients, and multiple regression analysis. Statistical significance was set at the 0.05 level.

Results

Descriptive statistics for the test indices are presented in Tables 1 and 2. The 3000 m run on each test occasion was significantly correlated with both W_{max_6} ($r=0.43$, $p<0.05$ and $r=0.56$, $p<0.01$) and W_{OBLA} ($r=0.51$, $p<0.01$ and $r=0.51$, $p<0.01$). The relationships were stronger when the W_{max_6} and W_{OBLA} values were expressed relative to body weight (Figs. 1 and 2).

Table 1. Descriptive statistics for field and laboratory tests W_{max_6} = calculated maximal power level that can be maintained for 6 min; HLa200 = lactate concentration at 200 W; HR 200 = heart rate at 200 W; RPE 200 = ratings of perceived exertion at 200 W; 3000 m = mean velocity while running 3000 m; I = first test occasion; II = second test occasion; 0 = at enlistment approximately one year before test I; Loaded = running with packs, boots and rifle

n	Variable		Units	Mean	SD	Range
47	W_{max_6}	0	$W \cdot kg^{-1}$	3.56	0.45	2.69–5.01
48		I	$W \cdot kg^{-1}$	3.66	0.45	2.71–4.51
32		II	$W \cdot kg^{-1}$	3.91	0.44	3.23–5.30
48	HLa 200	I	$mmol\ L^{-1}$	4.5	1.4	1.5–7.9
33		II	$mmol\ L^{-1}$	4.3	1.3	1.8–8.6
48	HR 200	I	$b \cdot min^{-1}$	158	11	130–185
33		II	$b \cdot min^{-1}$	155	13	130–182
48	RPE 200	I	Borg scale	4.9	1.3	2.5–9.0
33		II	Borg scale	5.0	1.5	3.0–9.5
34	3000 m	I	$m \cdot s^{-1}$	3.95	0.43	2.80–5.06
34		II	$m \cdot s^{-1}$	4.05	0.51	3.02–5.49
37	3000 m	Loaded	$m \cdot s^{-1}$	2.67	0.47	1.83–3.39

Table 2. Power output, RPE and HR at a blood lactate concentration of 4 mmol L^{-1} (OBLA) on the two test occasions

n	Variable		Units	Mean	SD	Range
48	W_{OBLA}	I	W	190	36	119–284
33		II	W	193	32	128–288
48	W_{OBLA}	I	$W \cdot kg^{-1}$	2.48	0.44	1.53–3.82
33		II	$W \cdot kg^{-1}$	2.51	0.34	1.96–3.55
48	RPE_{OBLA}	I	Borg scale	4.5	1.3	1.8–8.0
33		II	Borg scale	4.8	1.4	2.8–8.0
48	HR_{OBLA}	I	$bt \cdot min^{-1}$	155	12	126–185
33		II	$bt \cdot min^{-1}$	151	13	122–178

The W_{max_6}, W_{OBLA}, and HLa200 all demonstrated similar predictive power in accounting for the variation among subjects in the 3000 m run. The HR200 showed markedly lower predictive power (Table 3). Strong correlations were also

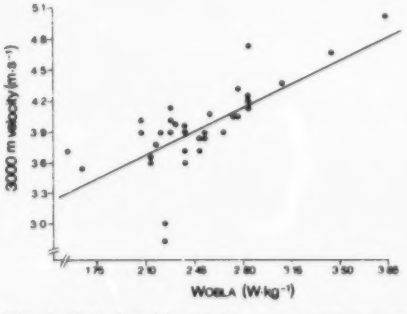

Fig. 1. Relationship of the average 3000 m run velocity to the power output corresponding to a blood lactate concentration of 4 mmol L^{-1} (W_{OBLA}) on the first test occasion. $r=0.70$, $p<0.001$, $y=2.265+0.673(x)$, $Sy.x=0.31$, $n=34$

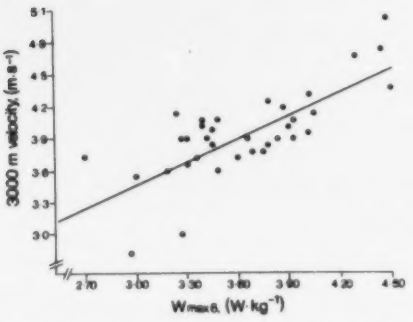

Fig. 2. Relationship of the average 3000 m run velocity to the power output estimated to lead to exhaustion after 6 min (W_{max_6}). $r = 0.75$, $p < 0.001$, $y = 1.281 + 0.732(x)$, Sy.$x = 0.29$, $n = 34$

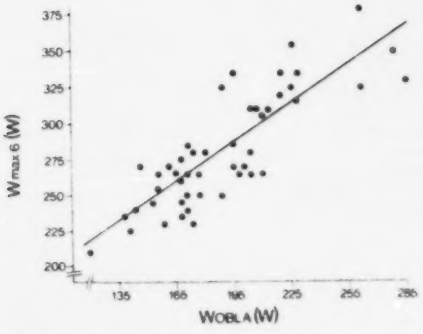

Fig. 3. Relationship of W_{OBLA} with W_{max_6} on the first occasion. $r = 0.84$, $p < 0.001$, $y = 107.4 + 0.912(x)$, Sy.$x = 21.7$, $n = 48$

evident between W_{max_6} and W_{OBLA} (Fig. 3) and between HLa200 and W_{OBLA} (Fig. 4).

The W_{max_6} values determined at the draft board test centres, approximately one year before the start of our study, were significantly related to each of the 3000 m runs (Table 3) in spite of the long interval between these tests.

The relationship between running performance in the field and the cycle ergometer test variables is complicated by the fact that body weight must be transported during running but not on a cycle ergometer. Therefore we have examined the relationship by expressing the cycle test variables as follows: a) the raw score without "correction" for body weight, b) per kg body weight, and c) by including body weight as a separate independent variable in multiple regression analysis. Table 3 demonstrates that the strength of the relationship increases when body weight is accounted for and that this is further enhanced by multiple regression analysis rather than by simply dividing the test indicator by body weight. A similar pattern was observed when the loaded 3000 m run was used as the dependent variable.

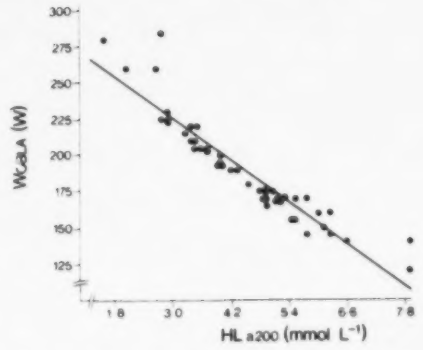

Fig. 4. Relationship of the lactate concentration at 200 W (HLa200) with W_{OBLA} on the first test occasion. $r = 0.94$, $p < 0.001$, $y = 298.5 - 24.25(x)$, Sy.$x = 12.0$, $n = 48$

Table 3. Correlation coefficients between selected laboratory test variables and velocity during the 3000 m runs

	3000 m I $m \cdot s^{-1}$			3000 m II $m \cdot s^{-1}$			Loaded 3000 m $m \cdot s^{-1}$		
	a	b	c	a	b	c	a	b	c
W_{max_6} 0	0.56	0.73	0.74	0.58	0.73	0.78	0.55	0.39	0.66
W_{max_6} I	0.43	0.75	0.84	0.26	0.55	0.73	0.58	0.54	0.68
W_{OBLA} I	0.51	0.70	0.83	0.43	0.61	0.81	0.63	0.57	0.77
HLa 200 I	−0.39	−0.25	0.72	−0.36	−0.25	0.69	−0.62	−0.55	0.80
HR 200 I	−0.26	0.03	0.67	−0.42	0.11	0.56	−0.59	0.42	0.52
W_{max_6} II	0.59	0.69	0.75	0.56	0.76	0.77	0.62	0.50	0.69
W_{OBLA} II	0.49	0.61	0.76	0.51	0.66	0.79	0.53	0.45	0.70

a = absolute value used for lab test variable
b = lab test variable expressed per kg body weight
c = both absolute value and body weight used as independent variables in multiple regression analysis

Discussion

The present study demonstrates that the blood lactate concentration during submaximal cycle ergometry can be used to predict cross-country running performance. Sixty-nine and 62% of the variation in running performance on the first and second test occasions, respectively, could be accounted for by the variation among subjects in the combination of W_{OBLA} and body weight. This was reduced somewhat when the loaded run performance was correlated with W_{OBLA} on the second test occasion, but still about one half of performance variation was explained solely by the combination of the W_{OBLA} and body weight values. Thus, the previously documented predictive power of blood lactate during treadmill ergometry for competitive running performance (Farrell et al. 1979; Föhrenbach et al. 1981; Sjödin and Jacobs 1981), has been extended to include the use of cycle ergometry for the evaluation of running performance. Moreover, the relationship seems applicable to running performance while load carrying.

The specificity of training effects dictates that subjects should be tested with treadmill ergometry if their running endurance is of interest. It is tempting to speculate that the predictive power of the lactate related variables would be increased by testing subjects during treadmill ergometry. Previous studies have reported that 80–90% of the variation in distance running performance in the field can be explained by the variation in the lactate response to treadmill running in the laboratory (Farrell et al. 1979; Sjödin and Jacobs 1981). Cycle ergometry, however, is the preferred exercise form for mass testing because of equipment costs, available space in test locales, subject safey, etc. The present results suggest that using lactate related variables such as W_{OBLA}, determined during cycle ergometry, is a satisfactory means of classifying subjects as to their capacity for cross-country running.

The problems with the W_{max}, the exhaustive exercise test presently employed at the recruitment centres, include the centres' requirement for a physician to continually be present during exhaustive exercise testing. Motivation of the subject to exert himself maximally is a prerequisite for a valid evaluation using any exhaustive exercise test. These problems would be obviated with a protocol similar to that used in the present study. Only submaximal exercise intensities are required to attain blood lactate concentrations of 4 mmol L^{-1}. This is attested to by the RPE values observed at W_{OBLA} (Table 2). The RPE values are similar to those reported by Noble et al. (1983) in a study which used a similar exercise protocol. RPE may, thus, provide a means of deciding when an exercise test to determine W_{OBLA} can be terminated. Another alternative is the use of a rapid lactate analyzer which assays the lactate concentration within two min of sampling — several such analysers are now available commercially. The strong correlation between HLa200 and W_{OBLA} confirms a previous study (Jacobs et al. 1983) and suggests that the multiple blood samplings required to determine W_{OBLA} could be reduced to a single sample at a standard power output without sacrificing predictive power.

The relationship between running velocity and W_{OBLA} or W_{max} was significant irrespective of whether or not the subjects were carrying the standard load during the run. The correlation coefficients were, however, reduced for the loaded run. This may be partially explained by the fact that the standard load represented a greater proportion of their body weight for the lighter subjects than for the heavier subjects. Hence the difference in exercise intensity between the loaded and unloaded runs was greater for those lighter subjects.

The fitness level of the participating subjects can be readily compared to several published studies where similar testing procedures have been employed. The W_{max} values in the present study were approximately 20% higher than that reported for 12,500 Swedish males registering for military service (Schéle et al. 1978). This is to be expected in light of their selection for military police training for which somewhat higher than average physical fitness criteria are required. However, their W_{OBLA} values are lower than those reported in two previous studies where males accustomed to hard physical exercise were tested with identical protocols (Jacobs and Kaiser 1982; Jacobs et al. 1983), yet higher than the values for 16 American soldiers (Tesch et al. 1981). The average velocity during the loaded run was within the range of that reported previously for 84 soldiers who ran 2800 m carrying 22 kg (3.07 ± 0.46 m · s^{-1}) (Nordesjö and Schéle 1974).

One might speculate that the physical fitness selection criteria for military police training created a relatively homogeneous group when compared with the total population of soldiers drafted annually. The testing of a larger, more heterogeneous group, such as a random sample of recruits tested annually in Sweden, would in-

crease the probability of observing a stronger relationship between the field and laboratory tests.

An additional question of interest was whether the W_{max_0} value determined at the time of enlistment would serve as an indicator of endurance exercise capacity at a later stage in the soldier's military service. Prior to induction a great variation in life style among the population would be expected accounting for the commensurate variation in fitness level. From the time of induction the soldiers are maintained in a far more controlled environment in terms of nutrition and physical activity patterns. The expected end result would be a smaller variation in fitness, i.e. the fitter subjects would become less fit and the less fit would improve through the enforced physical training programs. The results of the present study demonstrated that the average W_{max_0} values of the present group of subjects did not change significantly from the time of enlistment until our tests were performed some 12 and 17 months later. Hence, the classification of subjects into fitness categories at induction would seem to be a fair indication of their fitness level at a later stage of their military service.

In conclusion the results of this study demonstrated that the maximal exercise test presently employed in this country's recruitement centres could be replaced with the proposed submaximal test based on blood lactate concentrations, without a significant loss of predictive ability of running performance in the field.

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References

Borg G (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exercise 14:377–381

Dixon WJ, Brown MB (editors) (1979) Biomedical Computer Programs. University of California Press, Los Angeles

Farrell PA, Wilmore J, Coyle E, Billing J, Costill D (1979) Plasma lactate accumulation and distance running performance. Med Sci Sports 11:338–344

Föhrenbach R, Mader A, Hollman W (1981) Umfang und Intensität im Dauerlauftraining von Mittelstreckenläuferinnen des DLV und Maßnahmen zur individuellen Trainings- und Wettkampfoptimierung. Leistungssport 11:458–472

Jacobs I, Kaiser P (1982) Lactate in blood, mixed skeletal muscle, and FT or ST fibres during cycle exercise in man. Acta Physiol Scand 114:461–466

Jacobs I, Sjödin B, Schéle R (1983) A single blood lactate determination as an indicator of cycle ergometer endurance capacity. Eur J Appl Physiol 50:355–364

Jooste L, Van Der Linde A, Shapiro C, Strydom NB (1981) Metabolism of ultra long-distance running. In: Biochemistry of Exercise IV-A, edited by Poortmans J, Niset G, Baltimore: University Park Press, pp 93–99

Karlsson J, Jacobs I, Sjödin B, Tesch P, Kaiser P, Sahl O, Karlberg B (1983) Semi-automatic blood lactate assay: experiences from an exercise laboratory. Int J Sports Med 4:52–55

Kumagai S, Tanaka K, Matsuura Y, Matsuzaka A, Hirakoba K, Asana K (1982) Relationships of the anaerobic threshold with the 5 km, 10 km, and 10 mile races. Eur J Appl Physiol 49:13–23

Noble B, Borg G, Jacobs I, Ceci R, Kaiser P (1983) A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. Med Sci Sports Exercise 15:523–528

Nordesjö L-O (1974) Estimation of the maximal work rate sustainable for 6 min using a single-level load or stepwise increasing loads. Uppsala J Med Sci 79:45–50

Nordesjö L-O, Schéle R (1974) Validity of an ergometer cycle test and measures of isometric muscle strength when predicting some aspects of military performance. Forsvarsmedicin 10:11–23

Schéle R, Ahlborg B, Ekbom K (1968) Physical characteristics and allergic history in young men with migraine and other headaches. Headache 18:80–86

Sjödin B, Jacobs I (1981) Onset of blood lactate accumulation and marathon running performance. Int J Sports Med 2:23–26

Sjödin B, Jacobs I, Svedenhag J (1982) Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. Eur J Appl Physiol 49:45–57

Tesch PA, Sharp DS, Daniels WL (1981) Influence of fiber type composition and capillary density on onset of blood lactate accumulation. Int J Sports Med 2:252–255

Tornvall G (1963) Assessment of physical capabilities. Acta Physiol Scand [Suppl 201]

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